

## **Evaluation of Construction and Plugging Procedures for Well 373-35R in the CTV-Elk Hills Monterey Formation 26R Class VI Project**

This well construction and plugging evaluation report for the proposed Carbon TerraVault (CTV)-Elk Hills Class VI geologic sequestration (GS) project summarizes EPA's evaluation of several related activities associated with the construction and plugging of the 373-35R injection well that CTV will use to inject CO<sub>2</sub> into the Monterey Formation 26R Reservoir. This review also identifies preliminary questions for the applicant. CTV provided information about the construction of Well 373-35R in a document titled Well Construction, Operating, and Plugging (COP) Details, dated May 31, 2022 and in a confidential file entitled Injection & Monitoring Well Schematics, Elk Hills 26R Storage Project dated May 31, 2022.

CTV plans to inject CO<sub>2</sub> into the Monterey Formation 26R Reservoir via four injection wells, including one existing Class II injection well (373-35R) to be converted and three wells to be constructed (345C-36R, 353XC-35R, and 363C-27R). This construction and plugging evaluation report is specific to the Class VI permit for well 373-35R. There is some repetition between this evaluation and EPA's evaluation of the attachments relevant to the other proposed injection wells; however, this is necessary to provide a complete evaluation for each Class VI well permit record.

### **Injection Well Construction**

Well 373-35R is an existing Class II injection well that was drilled in 1982 and is currently permitted by CalGEM (California Geologic Energy Management Division) to inject water for pressure maintenance. CTV plans to repurpose Well 373-35R. The COP contains the following brief construction details regarding the repurposing of the 373-35R injection well:

1. The well design exceeds criteria of all anticipated load cases including safety factors.
2. Although no USDW is present, multiple cemented casing strings protect potential shallow USDW-bearing zones from contacting fluids within the production casing.
3. All casing strings were cemented in place with volume sufficient to place cement to surface using industry-proven recommended practices for slurry design and placement.
4. A cement bond log (CBL) indicates the presence of cement in the production casing annulus well above the Reef Ridge Shale confining layer and consistent with cementing operations results. Cement is present throughout the entire CBL logging interval within the Monterey and Reef Ridge formations (from base of 7" casing to ~6600 feet).
5. Upper completion design enables monitoring devices to be installed downhole, cased hole logs to be acquired, and planned mechanical integrity tests (MITs).
6. All wellhead equipment and downhole tubulars will be designed to accommodate the dimensions necessary for deployment of surface monitoring equipment with alarms and remote connectivity to a centralized facility.
7. Annular fluid (packer fluid) density and additives will mitigate corrosion.

The COP states that well materials will be compatible with the CO<sub>2</sub> injectate and will limit corrosion, including the use of: tubing constructed of corrosion resistant alloy based on injected CO<sub>2</sub> specifications; a packer made of corrosion resistant alloy and hardened rubber; casing and cement is constructed with N-80 and K-55 steel with Portland cement; and a wellhead constructed of stainless steel or other

corrosion resistant alloy based on injected CO<sub>2</sub> specification. All materials will meet API specifications, which is consistent with EPA guidance.

Table 1 of the COP presents information about the casing specifications, and Tables 2 and 3 describe the tubing and packer, respectively. The casing information presented in the narrative and tables is consistent with the well diagram.

The applicant provided a well diagram for Well 373-35R in the confidential file of Injection & Monitoring Well Schematics. While the diagram is not reproduced here to retain confidentiality, an evaluation in the context of other information in the permit application is provided. Relevant geologic formation tops were noted on the wellbore diagram. The average depth of the Upper and Lower Tulare Formation (the lowermost USDW in the Elk Hills Oil Field) within the AoR is 900-1,000 ft. (as reported on pg. 29 of the revised narrative, dated May 31, 2022). Pre-operational testing will help confirm whether the surface casing is sufficiently deep to protect the lowermost USDW (if one is present).

The depth to the Etchegoin Formation on the well diagram is consistent with information in the permit application narrative, and the depth of the Monterey Formation 26R Sands is within the range of depths reported on Table 1 of the narrative.

The surface and downhole pressure gauge and logging tool specifications detailed in Tables 8-14 of the quality assurance surveillance plan (QASP) are consistent with the well construction equipment and surface and subsurface temperature and pressure conditions.

Multiple sources of anthropogenic CO<sub>2</sub> are being considered for the Elk Hills 26R Injection Project. These include the Elk Hills NGCC Power Plant as well as third party existing and proposed industrial sources in the Southern San Joaquin Valley area. However, no specific information about the CO<sub>2</sub> content or any impurities was provided in the COP. The applicant states that a suitable corrosion-resistant alloy will be selected and installed once the CO<sub>2</sub> stream impurities and impurity concentrations have been determined. The Applicant also notes that the Class G Portland cement used to complete Well 373-35R, with cement to surface for each stage, has been used extensively in enhanced oil recovery injectors, and that the cement integrity is supported by a cement bond log (CBL) in Well 373-35R. However, the applicant did not provide a pre-operational testing plan that includes testing the compatibility of the injectate with well construction materials. Following the pre-construction measurement of the composition, properties, and corrosiveness of the injectate, the well construction materials and cement will need to be reviewed based on the results of these tests and prior to operation of Well 373-35R. (See the discussion of pre-operational testing below.)

The COP (pg. 4) states that “[s]ubsidence has not been observed historically in the areas around the injection wells because of hydrocarbon production, and shallow compression is not anticipated as a concern for casing or cement integrity.” However, the permit application narrative (on pg. 2) notes that the “...continuously subsiding [San Joaquin] basin is a sediment filled depression that lies between the Sierra Nevada and Coast Ranges and is 450 miles long by 35 miles wide.” The effects of subsidence on the mechanical integrity of injection wells has been cited as a concern in other California oil fields, and some operators have developed mitigation measures to relieve stress on the surface casing (e.g., via wellhead design that allows differential movement between the casings). Any design modifications to address the subsidence concern will need to meet the requirement that Class VI wells have cementing of the surface casing that extends to the surface.

### **Questions/Requests for the applicant:**

- *Please include the conductor casing grade on Table 1.*
- *Please submit procedures for any planned retrofitting of Well 373-35R.*
- *Please explain how the injection well's design will mitigate potential shallow compression as described on pg. 4 of the COP.*
- *Please provide evidence for the statement that land subsidence is not expected in a region that experiences subsidence and where fluids are being withdrawn.*
- *Please update item 4 under "materials" on pg. 3 to be consistent with the casing and cement materials in Table 1, which also describes the use of H-40 cement.*
- *Please discuss the duration that free phase water is expected to be present at the beginning of the injection phase and the corresponding impact on tubing integrity. For example, please provide additional discussion regarding the study of this phenomenon, e.g., in existing, nearby CO<sub>2</sub> injection wells.*
- *Please provide additional detail regarding the chemical and physical characteristics of the carbon dioxide stream as requested in the October 2022 Testing and Monitoring Evaluation.*

## Monitoring Well Construction

Schematics of the monitoring wells, including: the shallow monitoring well, well 355X-26R (the Etchegoin Formation monitoring well), and the three Monterey Formation monitoring wells (341-27R, 328-25R and 376-36R) were provided in a confidential file with information on wells in the AoR. All of the monitoring wells have been drilled and completed. See the Testing and Monitoring Evaluation for EPA's October 2022 evaluation of these wells.

## Injection Well Pre-Operational Testing

The COP for the 373-35R well describes logging and testing data that were acquired during the initial well construction or during subsequent operations. These tests include: deviation checks (during drilling); a cement bond log (CBL); open-hole well logs (e.g., spontaneous potential, natural gamma ray, and borehole caliper, resistivity, neutron porosity, and bulk density); and internal and external MITs, including standard annulus pressure testing (SAPT) and gas injection survey and temperature log. The SAPT was run for 30 minutes, and not the minimum of 60 minutes that is typical for the SAPT. However, CTV will conduct additional MITs prior to injection, so there is no concern at this point. Figure 1 shows the log and the location of the Reef Ridge Shale and Monterey Formation. Figure 2 shows the results of the CBL. According to the figure, it appears that the CBL was run from 6,600 feet to about 7,150 feet, which encompasses several hundred feet of the Reef Ridge Shale and the Monterey Formation..

The COP states that data not in the COP document and required by 40 CFR 146.87 will be addressed in the Pre-Operational Testing Plan. However, no planned well testing is described in the COP document for well 373-35R.

In the Testing and Monitoring Plan, CTV says that it "does not currently plan to complete pressure fall off testing" (pg. 10), given the extent of available information about the Monterey Formation 26R Reservoir. The plan also states that pressure fall off testing would be considered under decreasing injection rate and/or pressure increase outside of the modeling scenarios. However, a pressure fall off

test must be performed prior to injection, and included in the pre-operational testing plan. See the October 2022 Testing and Monitoring Evaluation for additional discussion.

### Objectives for Pre-Operational Testing

Based on the site characterization, AoR delineation modeling, and testing and monitoring evaluations, EPA has identified the following objectives for the planned pre-operational testing to address data gaps identified during the reviews. This information is summarized below (along with the planned tests that will address each data need that was described in the initial permit application materials submitted in November 2021) for reference and to clarify EPA's expectations for the updated materials that CTV must submit pursuant to 40 CFR 146.82(c) and 146.87.

#### Regional Geology and Geologic Structure

- Perform pressure build-up testing (anticipated testing method: pressure build-up test).
- Confirm the fracture pressure of the injection and confining zones (anticipated testing method: step-rate test in each zone using a representative fluid).

#### Geochemistry/Geochemical Data

- Establish baseline geochemistry for the Monterey Formation, as well as the Tulare and Etchegoin Formations for all analytes to be monitored during injection operations, per the Testing and Monitoring Plan (anticipated testing methods: various geochemical analyses).

#### Seismic History and Seismic Risk

- Establish baseline seismicity (anticipated testing method: existing seismic network/historic seismicity database).

#### Facies Changes in the Injection or Confining Zones

- Determine if there are any heterogeneities within the Monterey 26R injection zone that could affect its suitability for injection, including facies changes that could facilitate preferential flow (anticipated testing methods: pressure build-up test; planned and completed core, log, and seismic analysis).

#### CO<sub>2</sub> Stream Compatibility with Subsurface Fluids and Minerals

- Confirm the composition and water content of the CO<sub>2</sub> injectate as part of baseline sampling and verify that it will not react with the formation matrix (anticipated testing methods: various geochemical analyses, benchtop studies).
- Confirm that the properties of the CO<sub>2</sub> stream are consistent with the AoR delineation model inputs (anticipated testing methods: various geochemical analyses).
- Confirm that the analytes for injectate and ground water quality monitoring are appropriate based on the results of the geochemical modeling evaluation (anticipated testing methods: various geochemical analyses).

#### Confining Zone Integrity

- Collect baseline pressure data in the Etchegoin Formation to support upward confinement between the Monterey and shallower formations (anticipated testing method: pressure build-up test).
- Determine the porosity and permeability of the Reef Ridge Shale at the location of each of the 26R project wells (anticipated testing methods: core and log data during well drilling).

- Test for changes in capillary entry pressure of the Reef Ridge Shale due to reaction of the shale with the injectate (anticipated testing method: mercury injection capillary pressure).

#### Injection Well Construction

- Following the pre-construction measurement of the composition, properties, and corrosiveness of the injectate, review the well construction materials and cement in the context of the results of these tests (anticipated testing methods: various geochemical analyses).

#### Monitoring Well Pre-Operational Testing

No pre-operational well testing is described for any of the monitoring wells (i.e., the planned Upper Tulare Formation monitoring well, Well 355X-26R in the Etchegoin Formation, or Wells 341-27R, 328-25R and 376-36R in the Monterey Formation) within the COP for well 373-35R.

Demonstration of mechanical integrity will need to be conducted prior to injection operations; see the October 2022 Testing and Monitoring Evaluation for additional information.

#### *Question/Request for the applicant:*

- *If any retrofitting of the existing well occurs, please describe in the Well Construction Plan the pre-operational testing to be performed after conversion of the 373-35R well, including MITs, testing to confirm the compatibility of the well materials with the CO<sub>2</sub> stream, and the formation testing required at 40 CFR 146.87.*
- *Please describe in the Well Construction Plan the pre-operational testing procedures to be performed on the monitoring wells.*

#### Injection Well Plugging Plan

Plugging details for Well 373-35R are provided in Table 6 of the COP. Before plugging the injection well, CTV will determine the bottom-hole pressure needed to successfully squeeze cement for plugging operations. At least one external MIT will be conducted prior to plugging, including but not limited to a temperature log that will be run over the entire depth of the well and the results will be compared to temperature logs performed before and during CO<sub>2</sub> injection. Generic procedures for plugging the well are described. Specific plugging procedures will need to be submitted to and approved by EPA prior to plugging operations.

CTV states that, prior to plugging, a kill fluid will be “bullheaded” into the wellbore to prevent reservoir fluid inflow and provide a buffer to flush the wellbore. During plugging operations, the cement slurry and displacement fluids will be over-balanced to prevent reservoir fluids from entering the wellbore during cementing operations.

The plugging details listed in Table 6 of the COP are consistent with injection well construction details, and the abandonment schematic of the Appendix provided in the CBI file.

The COP states that Plug #1 (bottom-hole cement plug) will cover all perforations and will extend at least 100 ft. above the uppermost perforations, the casing cementing point, the water shut-off holes, or the oil or gas zone, whichever is highest.

The COP also states that the base of the USDW will be covered by Plugs #2 and #3. If cement exists behind the casing and across the base of the USDW, a 100 ft. cement plug will be placed inside the

casing across this interface. If the top of cement behind the casing is found to be below the base of the USDW, a cement squeeze will be performed through the perforations. Additionally, a 100 ft. cement plug will be placed inside the casing across the freshwater-saltwater interface. However, the application narrative asserts that there is no USDW within the AoR of the CTV 26R project (and therefore does not provide a depth to the base of the lowermost USDW. Based on information in the permit application narrative, the base of the Tulare Formation is between 900 and 1,000 ft. (Based on the aquifer exemption record of decision for the Elk Hills Oil Field, the Upper Tulare—the lowermost USDW—is shallower than 400 feet.) Plug #3, and the corresponding well construction and plugging information may need to be updated accordingly to ensure that the plug extends 100 feet below the base of the USDW, if one is present.

Plug #4 (the surface plug) will plug the casing at the surface with at least 25 ft. of cement.

All cement plugs will be composed of a Class G Portland cement blend that has a minimum 1,000 psi compressive strength and a maximum liquid permeability of 0.1 mD. The applicant states that the cement blend for the plugs will be equivalent to the properties of the Class G Portland that was used for well construction, and is resistant to CO<sub>2</sub>.

The plugging procedures that will be used to emplace these plugs appear to be acceptable, provided responses to the questions below are adequate.

***Questions/Requests for the applicant:***

- *Please confirm that wellbore flushing/bullheading technique described will be conducted at rates that will not cause fracturing of the surrounding formations or compromise any plug installation.*
- *The COP details state (on pg. 17) that a 100 ft. cement plug will be placed inside the casing across the freshwater-saltwater interface. If there is no USDW, to what layer does this refer?*
- *For completeness, please add the surface restoration details described on the well schematics to the COP narrative.*
- *Please provide a stand-alone document that describes the plugging procedures for attachment to a Class VI permit.*

## Monitoring Well Plugging Plan

For the Etchegoin and Monterey monitoring wells, the schematics include a table with information about the depth of each of four plugs, and the potential method of emplacement (i.e., balanced plug retainer or CT plug). CTV needs to provide specific procedures prior to plugging each well. All of the monitoring wells are planned to be plugged with Class G cement, which is corrosion resistant and suitable for CO<sub>2</sub> injection projects.

CTV plans to plug the Etchegoin Formation monitoring well with one plug within the surface casing, and three plugs within the long-string casing (including the bottom plug in the Etchegoin Formation). Each of the Monterey Formation monitoring wells will have one plug within the surface casing, one plug within the intermediate casing, and two plugs within the long-string casing (including the bottom plug in the Monterey Formation). The information shown is consistent with the well construction diagrams.

Each schematic indicates that there is no USDW in the area, which will be confirmed during pre-operational testing. The schematics also indicate that casing will be cut to five feet below ground surface, a cap welded to the well, and the land surface will be backfilled and reclaimed.

A plugging schematic is provided for the shallow monitoring well. However, it contains no information about plugging, procedures, the depth of the plugs, the type of cement, or cement emplacement measurement procedure to be used.

***Questions/Requests for the Applicant:***

- *Please provide information about the plugs for the shallow monitoring well, similar to those for the deeper monitoring wells.*
- *Please provide a narrative description of the plugging procedures for the Etchegoin and Monterey Formation monitoring wells.*
- *Please confirm that surface reclamation will be completed to restore the site to “pre-operation conditions.”*

***Considerations based on the results of Pre-Operational Testing/Modeling Updates:***

- *EPA will need to review the plugging procedures based on updated geologic information (including information about the presence of a USDW) and construction schematics after the pre-operational testing occurs.*